Antenna Incorporation in the Hinge of a Laptop Computer

Title: RECONFIGURABLE ANTENNA FOR INCORPORATION IN THE HINGE OF A LAPTOP COMPUTER

Abstract: There is disclosed an antenna system suitable for incorporation between the hinges joining a lid portion and a keyboard portion of a laptop computer. The antenna system is disposed on an elongate dielectric substrate having a longitudinal axis with first and second opposed ends and a predetermined reference point therebetwixt. The antenna system comprises a compound antenna structure disposed substantially laterally symmetrically about the reference point on the substrate, the compound antenna structure comprising at least a first unbalanced antenna with a first feed and a further antenna with a second feed; and first and second additional unbalanced antennas disposed substantially laterally symmetrically about the compound antenna structure on the longitudinal axis of the substrate, each of the first and second additional unbalanced antennas having a respective feed.

FIG. 1
RECONFIGURABLE ANTENNA FOR INCORPORATION IN THE HINGE OF A LAPTOP COMPUTER

This invention relates to a reconfigurable antenna system. Particularly, but not exclusively, the invention relates to a reconfigurable multiple-input multiple-output (MIMO) antenna system for use in a portable electronic device such as a laptop computer with a lid incorporating a display that is connected by a hinge to a body incorporating a keyboard.

BACKGROUND

[001] Portable devices such as smartphones and laptops need a number of antennas to be positioned close together while avoiding coupling between them. A variety of isolation means are known in the art, including resonators positioned between a first and a second antenna to increase the isolation between the two antennas. The resonators typically comprise a conductor having a length tuned to the frequency band in which isolation is required, which may take a variety of forms, such as an inverted L shape, grounded at the end of one of the arms, such as the free end of the longer arm, positioned between the first and the second antennas. Further structures are known, such as ground planes that, when positioned between a first and second antennas, will provide isolation between them. Typically, however, such structures operate well only in a limited frequency band, outside which isolation is significantly reduced. This is a significant obstacle in the design of compact multi-frequency band antenna systems, such as MIMO antenna systems to cover multi global wireless standards.

[002] The use of metal monocoque ('unibody') chassis for portable devices such as laptop computers restricts the positioning of antennas to regions behind non-metallic components, such as polymer inserts into the chassis, or polymer components used as part of the hinge between the keyboard and screen part of the chassis. Multi-band MIMO antenna systems for laptops operating in the LTE low band, mid band and WLAN band comprising radiators placed in the hinge region of the laptop are known, as disclosed for example in WO2013060683 (Krewski et al.). These prior art designs are limited in the need for a conductive coupling between the two parts of the chassis formed by the hinges, which is an undesirable design constraint, and by the positioning of the hinges, which sensitively affects the operation of the antenna system. Such design constraints render the prior art designs too narrow in scope to accommodate the range of design concepts required by manufacturers. Additionally, the feed ports in the prior art design require a first connection
to the keyboard part of the chassis, and a second connection to the screen part of the chassis, which requires a cumbersome RF electrical connection between the two parts.

[003] A further challenge is to provide a multi-band MIMO antenna system that is compact enough to fit within the hinge region of a laptop, comprising two WLAN antennas and two LTE cellular antennas, each capable of independent operation in different frequency bands, with sufficient isolation between the antennas. In particular, the hinge presents a constrained length, and the antennas need to be disposed within the length while being isolated one from another. Conventionally, isolation is achieved by providing a first WLAN antenna and a first LTE antenna within the hinge region, and a second WLAN antenna and a second LTE antenna within either the keyboard or the screen part of the chassis. The use of metallic monocoque chassis however means that all four antennas need to be provided within the hinge region.

[004] Accordingly, embodiments of the present disclosure seek to provide improved antenna systems comprising multiple antennas, and optionally one or more isolation structures to improve isolation between the antennas. Certain embodiments of the disclosure provide an improved 4 port multi-band MIMO antenna system for use in laptops, in which the radiating elements are provided within the hinge region of the laptop, without the need for electrical connection between the two parts of the laptop chassis.

BRIEF SUMMARY OF THE DISCLOSURE

[005] In the context of the present application, a "balanced antenna" is an antenna that has a pair of radiating arms extending in different, for example opposed or orthogonal, directions away from a central feed point. Examples of balanced antennas include dipole antennas and loop antennas. In a balanced antenna, the radiating arms are fed against each other, and not against a groundplane. In many balanced antennas, the two radiating arms are substantially symmetrical with respect to each other, although some balanced antennas may have one arm that is longer, wider or otherwise differently configured to the other arm. A balanced antenna is usually fed by way of a balanced feed. A balanced loop antenna may be understood to be a loop antenna with a balanced feed.

[006] In contrast, an "unbalanced antenna" is an antenna that is fed against a groundplane, which serves as a counterpoise. An unbalanced antenna may take the form of a monopole antenna fed at one end, or may be configured as a centre fed monopole or otherwise. An unbalanced antenna may be configured as a chassis antenna, in which the antenna generates currents in the chassis of the device to which the antenna is attached, typically a groundplane of the device. The currents generated in the chassis or groundplane
give rise to radiation patterns that participate in the transmission/reception of RF signals. An unbalanced antenna is usually fed by way of an unbalanced feed.

[007] A balun may be used to convert a balanced feed to an unbalanced feed and vice versa.

[008] A reconfigurable antenna is an antenna capable of modifying dynamically its frequency and radiation properties in a controlled and reversible manner. In order to provide a dynamical response, reconfigurable antennas integrate an inner mechanism (such as RF switches, varactors, mechanical actuators or tuneable materials) that enable the intentional redistribution of the RF currents over the antenna surface and produce reversible modifications over its properties. Reconfigurable antennas differ from smart antennas because the reconfiguration mechanism lies inside the antenna rather than in an external beamforming network. The reconfiguration capability of reconfigurable antennas is used to maximize the antenna performance in a changing scenario or to satisfy changing operating requirements.

[009] A chassis antenna may be understood to be an antenna that uses the groundplane as a counterpoise and excites particular radiating modes in the groundplane.

[010] Viewed from a first aspect there is provided an antenna system disposed on an elongate dielectric substrate having a longitudinal axis with first and second opposed ends and a predetermined reference point therebetween, the antenna system comprising:

i) a compound antenna structure disposed substantially laterally symmetrically about the reference point on the substrate, the compound antenna structure comprising at least a first unbalanced antenna with a first feed and a further antenna with a second feed; and

ii) first and second additional unbalanced antennas disposed substantially laterally symmetrically about the compound antenna structure on the longitudinal axis of the substrate, each of the first and second additional unbalanced antennas having a respective feed.

[011] Viewed from a second aspect, there is provided a laptop computer comprising a lid portion attached to a keyboard portion by way of a hinge mechanism incorporating an antenna system according to the first aspect.

[012] The hinge mechanism may comprise first and second hinges spaced apart from each other along a hinge axis between the lid portion and the keyboard portion, and the antenna system may be disposed between the first and second hinges.
Viewed from a third aspect, there is provided a portable device comprising an antenna system as described hereinabove, and further comprising first and second conductive case components hinged together, the antenna system being disposed in the hinge region between the adjacent edges of the first and second case components.

The first and second conductive case components may be hinged together by way of first and second hinges spaced apart from each other along a hinge axis between first and second case components, the antenna system being disposed in the hinge region between the adjacent edges of the first and second case components.

 Advantageously, the first unbalanced antenna and the further antenna of the compound antenna structure are configured to excite substantially orthogonal modes or radiation patterns. This helps to promote isolation between the antennas of the compound antenna structure.

Isolation between the first and second additional unbalanced antennas may further be improved by the provision of one or more conductive resonators on the substrate between each of the first and second additional unbalanced antennas and the compound antenna structure. In some embodiments, the conductive resonators may be substantially L-shaped or T-shaped, with one arm extending along the longitudinal axis and the other arm extending substantially perpendicular thereto. Other configurations are also envisaged. The conductive resonators may be arranged in a substantially symmetrical configuration about the central point.

In certain embodiments, first and second different conductive resonators may be provided between each of the additional unbalanced antennas and the central compound antenna structure. The first and second different conductive resonators may have different shapes and/or lengths. In one advantageous embodiment, the first conductive resonators are shorter in length than the second conductive resonators. The first conductive resonators are configured to resonate mainly at 5.5GHz, while the second, longer conductive resonators are configured to resonate mainly at 2.4GHz. The closer the resonators are located to the first and second additional unbalanced antennas, the more current they are able to couple.

The first and second additional unbalanced antennas may be configured, together with the resonators, to generate radiation patterns directed primarily away from each other along the longitudinal axis. This helps to improved isolation between the antennas.

In certain embodiments, it is possible to obtain isolation of more than 20dB between the first and second additional unbalanced antennas.

In some embodiments, at least some of the conductive resonators are connected to ground, for example to the main groundplane. Grounded resonators typically work at a
quarter wavelength, which means that they can be made smaller than equivalent floating (non-grounded) resonators. The conductive resonators may be connected directly to ground, or by way of an impedance, such as a fixed or a selectable variable impedance.

[021] The further antenna of the compound antenna structure may be configured as a second unbalanced antenna. In such embodiments, the first and second unbalanced antennas of the compound antenna structure are preferably arranged substantially symmetrically about the reference point along the longitudinal axis.

[022] In other embodiments, the further antenna of the compound antenna structure is configured as a balanced antenna.

[023] The predetermined reference point may be located substantially centrally on the longitudinal axis of the substrate, or may be to one or other side of a central point on the longitudinal axis of the substrate. What is important is that the compound antenna structure displays substantial mirror symmetry about the reference point and that the first and second additional unbalanced antennas display substantial mirror symmetry about the reference point, although the entire antenna structure may be displaced towards the first or the second end of the substrate. Moreover, when the antenna system is installed between first and second conductive hinges between the lid portion and keyboard portion of a laptop computer, it is important that the reference point is centrally positioned between the first and second hinges.

[024] The substrate comprises a dielectric material, and has an elongate structure defining a lateral or longitudinal extent or direction. The substrate may be generally rail- or bar-like in shape, or may be substantially planar or slab-like, and be adapted or configured for incorporation into a hinge mechanism between a screen and a keyboard of a laptop computer. The substrate may comprise a main groundplane in the form of an electrically conductive track that is maintained at RF ground. The main groundplane is preferably also symmetrical about the reference point, and extends along the longitudinal axis. Alternatively, a groundplane defined by or in the lid portion or the keyboard portion may be utilised as a main groundplane.

[025] Herein for clarity a lateral direction is between the left and right sides along the longer length of the substrate, and a vertical direction is substantially perpendicular to the lateral direction. The substrate may be substantially planar and may have a thickness, or may be a three dimensional body having front and rear faces joined by an upper and a lower surface. The antennas and resonator elements may be disposed on one of both of the front and rear faces and may extend over the upper or lower faces, depending on operational and physical requirements.
[026] The compound antenna structure may be configured as a Long Term Evolution (LTE) antenna. The compound antenna structure may be configured as a two-port antenna, one port comprising or being connected to the first feed and the other port comprising or being connected to the second feed.

[027] The balanced antenna of the compound antenna structure may comprise a dipole antenna disposed longitudinally and substantially symmetrically about the second feed. The dipole antenna may comprise at least first and second arms fed together by the second feed and extending respectively away from each other towards the first and second opposed ends of the substrate. The first and second arms may both be substantially straight, or may both have a meandering configuration, although they should be substantially symmetrical about the second feed.

[028] In some embodiments, the first and second arms of the dipole antenna may be grounded, for example by terminating at a conductive groundplane (for example the main groundplane of the antenna system) or being shorted thereto by way of conductive components. This arrangement means that it is possible to avoid the use of balun components, which might unduly narrow the bandwidth, introduce RF losses and add cost.

[029] Alternatively, the balanced antenna may be configured as a loop antenna. In some embodiments, part of the loop antenna is formed by first and second arms that are fed together at the second feed and extend respectively away from each other towards the first and second opposed ends of the substrate before turning back towards each other to complete the loop. Alternatively, the first and second arms may extend away from each other before turning through an angle, for example a right angle, so as to connect to an edge of a main groundplane, the edge of the main groundplane serving to complete the loop of the loop antenna.

[030] In some embodiments, the balanced antenna may comprise more than one radiating element, for example a pair of dipole antennas, or a pair of loop antennas, or a dipole antenna in combination with a loop antenna. Optionally, the balanced antenna may additionally comprise one or more parasitic radiating elements, for example in the form of metal wire, folded metal wire, dipole, folded dipole or any other suitable parasitic elements. In some embodiments, the parasitic element may comprise a resonator loaded with a passive impedance, for example lumped capacitors and/or inductors. Where the balanced antenna comprises more than one radiating element, the different radiating elements can operate in different frequency bands.

[031] The unbalanced antenna of the compound antenna structure may be configured as a monopole or chassis antenna. In some embodiments, the unbalanced antenna takes the form of a centre-fed monopole disposed substantially symmetrically about the reference
point on the substrate. The centre-fed monopole may take the form of a conductive strip or track arranged substantially parallel to the longitudinal axis of the substrate. The unbalanced antenna is driven against a groundplane, for example the main groundplane of the antenna system.

[032] The second feed for the balanced antenna may be provided on a PCB or the like located centrally on the elongate substrate. The PCB may be shaped so as to conform to a surface of the elongate substrate. For example, the PCB may have an L-shaped profile. The PCB may comprise or constitute at least one groundplane that is separate from the main groundplane of the substrate of the antenna system. Matching circuitry for the balanced antenna can be located on the at least one groundplane of the PCB. In one embodiment, the PCB may comprise first and second substantially coplanar groundplanes disposed next to each other in a substantially symmetric configuration about the reference point, with the first arm extending from the first groundplane and the second arm extending from the second groundplane. The matching circuitry may be disposed on the first groundplane, and an RF feed cable may be arranged so as to follow a path of the first arm of the balanced antenna before connecting to one side of the matching circuitry. The other side of the matching circuitry is then connected to the second groundplane. A dummy RF feed cable may be arranged to follow the path of the second arm so as to maintain symmetry. The second groundplane is provided primarily to preserve symmetry with respect to the first groundplane.

[033] Advantageously, the balanced antenna and the unbalanced antenna of the compound antenna structure are configured to excite substantially orthogonal modes, which helps to isolate the antennas of the compound antenna structure from each other.

[034] The first and second additional unbalanced antennas may be configured as grounded monopole antennas, for example M-shaped monopoles or dual band PIFAs, driven against a groundplane which may be the same as or different to the groundplane against which the unbalanced antenna of the compound antenna structure is driven. In certain embodiments, all of the unbalanced antennas are driven against the same main groundplane of the antenna system.

[035] Advantageously, the first and second additional unbalanced antennas are configured as dual-band grounded monopole antennas, for example being configured for operation in both the 2.4 and 5.5GHz WLAN WiFi bands. In one embodiment, the first and second additional unbalanced antennas may be configured as PIFAs comprising first and second branches. The first branch may include a feed connection and a connection to ground, and the second branch may extend from the first branch. One of the first and second branches may be configured to operate in a higher frequency band (e.g. 5.5GHz) and the other may
be configured to operate in a lower frequency band (e.g. 2.4GHz). The branch operating in
the higher frequency band may be shorter than the branch operating in the lower frequency
band. The efficiency of each additional unbalanced antenna can be improved by increasing
the width of each branch, and optionally increasing the width of the feed and ground
connections. In some embodiments, the first and second additional unbalanced antennas
are tuned so as to provide a good impedance match in both the lower and the higher
frequency band at the same time. In some embodiments, this can be achieved by
appropriate antenna geometry without the need for an extra matching circuit.

[036] Alternatively, the first and second additional unbalanced antennas may each be
configured as substantially symmetric (along the longitudinal axis) grounded monopole
antennas. For example, the additional unbalanced antennas may each comprise an
elongate strip with first and second end extending along the longitudinal axis and provided
with a central feed. The elongate strip may be connected to ground at its first and second
ends. Alternatively, the elongate strip may be connected to ground at points between each
of the first and second ends and the central feed. An advantage of using symmetric
grounded monopole antennas as the first and second additional unbalanced antennas is
that these antennas have excellent isolation from each other, especially when the antenna
system as a whole is installed in a hinge region of a laptop computer having two large
groundplanes, one in the lid section and one in the keyboard section. This is because the
gap between the two large groundplanes will support a transmission mode, and each
symmetric grounded monopole antenna will excite a mode that is substantially symmetric
with respect to the antenna, this mode being an even mode. As such, the even mode is not
easily coupled between the first and second symmetric grounded monopole antennas, thus
improving isolation between the antennas.

[037] In a preferred embodiment, the antenna system comprises, disposed from left to right
on a common substrate, the first additional unbalanced antenna, being a dual band WLAN
antenna; at least one conductive resonator; the compound antenna structure, being a two
port LTE antenna; at least one conductive resonator in mirror symmetry with the at least one
conductive resonator between the first unbalanced antenna and the compound antenna
structure; and the second additional unbalanced antenna, being a dual band WLAN antenna.

[038] The antenna system as above may be substantially or wholly symmetrical about a
vertical centre line of the substrate.

[039] The substrate may comprise a single contiguous insulating material element on
which all the conductive resonator and antenna elements are formed, or may comprise an
assembly of a plurality of sub-components, each having one or more of the antennas,
isolation structures, or resonator elements formed or mounted thereon. It is envisaged that
in typical embodiments the antennas and isolation structures may be formed on a common substrate by a metal deposition process such as printing, electroplating or electroless plating, though embodiments are not limited to the method of fabrication, and antenna systems in which one or more free standing conductive elements are disposed to form the features of the inventive system are included in scope. The substrate may be a planar or a 3D substrate with the antennas and conductive resonator elements formed on the planar or 3D surface such that they are adjacent to and spaced apart from each other. In this way coupling can be provided between portions of the antennas and conductive resonator elements, and between multiple conductive resonator elements, so as to provide the desired isolation between the antennas. Such coupling and isolation may be derived from the planar or 3D structure using methods known in the art, allowing the planar or 3D structure to be designed and optimised. Where a main groundplane is provided on the substrate, this may also be formed by a metal deposition process as described above.

[040] In some embodiments the antenna system comprises a first conductive sheet component located adjacent to the top side of the substrate and a second conductive sheet component located adjacent to the bottom side of the substrate, the conductive sheet components being for example part of a case of a portable device such as a laptop. The antenna system is preferably designed and optimised for operation when mounted in the vicinity of the first and second sheet components.

[041] The antenna system may form part of a portable device having a conductive first and second case components hinged together, the antenna system being located in a gap between the first and second case components, such as in the hinge region. The antenna system may form part of a hinge component that attaches the two case components.

BRIEF DESCRIPTION OF THE DRAWINGS

[042] Embodiments of the invention are further described hereinafter with reference to the accompanying drawings, in which:

Figure 1 shows a laptop computer in outline, indicating a location for an antenna system of the present application.

Figure 2 shows the antenna system of Figure 1 in more detail.

Figure 3 shows a radiation pattern of one of the additional unbalanced antennas of the Figure 2 embodiment.

Figure 4 shows one of the additional unbalanced antennas in more detail.

Figure 5 is an S-parameter plot for the embodiment of Figure 4.
Figures 6 and 7 show the central compound antenna structure of the Figure 2 embodiment in more detail.

Figure 8 shows a second embodiment of the antenna system of Figure 1.

Figure 9 shows a third embodiment of the antenna system of Figure 1.

Figure 10 is an S-parameter plot for the embodiment of Figure 9.

Figure 11 shows a fourth embodiment of the antenna system of Figure 1.

Figure 12 shows a fifth embodiment of the antenna system of Figure 1.

Figure 13 shows a sixth embodiment of the antenna system of Figure 1.

Figure 14 shows a seventh embodiment of the antenna system of Figure 1.

Figure 15 shows an eighth embodiment of the antenna system of Figure 1.

Figure 16 shows a ninth embodiment of the antenna system of Figure 1.

Figure 17 shows a tenth embodiment of the antenna system of Figure 1.

Figure 18 shows an eleventh embodiment of the antenna system of Figure 1.

Figure 19 shows a twelfth embodiment of the antenna system of Figure 1.

Figure 20 shows a thirteenth embodiment of the antenna system of Figure 1.

DETAILED DESCRIPTION

[043] Figure 1 shows a laptop computer 1 in schematic form. The laptop computer 1 comprises a lid portion 2 attached to a keyboard portion 3 by way of hinges 50. The lid portion 2 contains a screen (not shown), while the keyboard portion 3 includes a keyboard (not shown) and a main PCB (not shown) for the various power, processing and memory components of the laptop computer 1. In a typical laptop computer 1, the lid portion 2 and the keyboard portion 3 each include a large groundplane (not shown) for the various electronic components. Moreover, some laptop computers have a metal casing, which means that the lid portion 2 and the keyboard portion 3 each define a large conductive plane.

[044] An antenna system 4 of the present disclosure is disposed between the hinges 50 in a gap between the lid portion 2 and the keyboard portion 3. The antenna system 4 comprises an elongate dielectric substrate 5 with a two port LTE antenna 6 located between first and second WLAN/WiFi antennas 7 in a symmetrical arrangement.

[045] Figure 2 shows the antenna system 4 in more detail. The elongate dielectric substrate 5, which may be made of plastic or another suitable dielectric material, has a
longitudinal axis, first and second ends 8, 9 and a predetermined reference point 10 defining a centre of mirror symmetry for the antenna system 4. The predetermined reference point 10 need not be centrally located between the first and second ends 8, 9, although typically it will define a centre point along the longitudinal axis of the substrate 5. This is because the hinges 50 may include metal components, and it is desirable for the various antennas 6, 7 to be arranged symmetrically between any metal components in the hinges 50 so as to promote good isolation and appropriately directed radiation patterns.

[046] The two port LTE antenna 6 comprises a balanced antenna 11 with first and second arms 12 driven against each other by a balanced feed 13, and an unbalanced antenna 14 driven against a main groundplane (not shown) by an unbalanced feed 15. The two port LTE antenna 6 is arranged symmetrically about the reference point 10.

[047] The WLAN/WiFi antennas 7 each comprise an unbalanced antenna driven against the main groundplane (not shown) by an unbalanced feed (not shown), and are arranged one on either side of the two port LTE antenna 6, and display mirror symmetry about the reference point 10.

[048] The WLAN/WiFi antennas 7 are isolated from each other by way of conductive resonators 51 disposed on the substrate 5 between the WLAN/WiFi antennas 7 and the two port LTE antenna 6. The conductive resonators 51 also display mirror symmetry about the reference point 10.

[049] Figure 3 illustrates an exemplary radiation pattern generated by the left hand WLAN/WiFi antenna 7 of the antenna system 4 shown in Figure 2. It can be seen that the radiation pattern is beamed generally along the longitudinal axis in a direction towards the first end 8 of the substrate 5. The right hand WLAN/WiFi antenna will generate a similar radiation pattern, but beamed in the opposite direction towards the second end 9 of the substrate 5. Configuring the WLAN/WiFi antennas to generate radiation patterns that are directed in opposed directions helps to improve isolation.

[050] Figure 4 shows the first end 8 of the substrate 5 in more detail. The substrate 5 in this particular embodiment is configured as a hollow rail having a D section, but other configurations are of course possible. The left hand WLAN/WiFi antenna 7 in this embodiment is configured as a grounded monopole antenna, specifically a PIFA having first and second branches 16, 17. The first branch 16 includes a feed connection 18 and a shorting connection 19 connected to a main groundplane 20, in this case formed in or by the lid portion 2. The feed connection 18 and shorting connection 19 are situated close to each other. The groundplane 20 may be a groundplane defined by the lid portion 2 or keyboard portion 3 of the laptop computer 1. The second branch 17 extends from the first branch 16 and runs substantially parallel thereto. The second branch 17 may be folded down at its
distal end 21, thus allowing the second branch 17 to be made longer than the first branch 16 without taking up too much additional space along the longitudinal axis of the substrate 5. The shorter, first branch 16 is configured to operate in a higher frequency band, for example 5.5GHz, while the longer, second branch 17 is configured to operate in a lower frequency band, for example 2.4GHz, although it will be appreciated that coupling between the two branches 16, 17 is not insignificant and needs to be taken into account in the design of the WLAN/WiFi antenna 7. In the embodiment shown, there is no need for an external matching circuit for the WLAN/WiFi antenna 7, which can be tuned by design so that it is impedance matched in both the 2.4GHz and 5.5GHz WLAN/WiFi bands simultaneously.

[051] Also shown in Figure 4 are first and second conductive resonators 22, 23, which in this embodiment are configured as inverted L structures with one arm connected to the groundplane 20 and the other arm extending along the longitudinal axis of the substrate 5. The resonators 22, 23 are disposed between the WLAN/WiFi antenna 7 and the compound antenna structure 6 (not shown in Figure 4).

[052] The arrangement of the two WLAN/WiFi antennas 7 and the resonators 22, 23 can provide isolation of over 20dB between the antennas 7. The S-parameter simulation results for the embodiment of Figure 4 are shown in Figure 5, with the S44 return loss plot for the WLAN/WiFi antenna 7 indicated at 24. It can be seen that the antenna 7 is effective at 2.4GHz and 5.5GHz.

[053] Figures 6 and 7 show a central portion of the antenna system 4 in more detail. The two port LTE antenna 6 in this embodiment includes, as the balanced antenna, a loop antenna with first and second arms 12 driven against each other by a balanced feed 13. Distal ends 25 of the first and second arms 12 are connected to the main groundplane 20, the edge of which completes the loop of the loop antenna. An L-shaped PCB 26 is shaped to conform to an edge region of the substrate 5 at the reference point 10. First and second separate groundplanes 52, 53 are formed on the PCB 26 and disposed symmetrically about the reference point 10. An RF feed cable 54 for the first feed of the two port LTE antenna 6 follows the path of the first arm 12 and connects to a matching circuit 55 provided on an underside of the first separate groundplane 52. An output from the matching circuit 55 is connected at 56 to the second separate groundplane 53. A dummy RF feed cable 57 follows the path of the second arm 12 to maintain symmetry about the reference point 10. It can be seen that the first feed comprises a balanced feed.

[054] The unbalanced antenna of the two port LTE antenna 6 is formed as a centre-fed monopole antenna 28 having an unbalanced feed 29 and driven against the main groundplane 20.
[055] An alternative to the embodiment of Figures 4, 6 and 7 is shown in Figure 8, with the WLAN/WiFi antennas 7 configured as symmetric grounded monopole antennas. Here, each WLAN/WiFi antenna 7 comprises a centre-fed monopole 30 with a feed 31, first and second arms 32, and connectors 33 connecting distal ends of the first and second arms 32 to the main groundplane 20. The two port LTE antenna 6 in this embodiment may comprise a grounded dipole antenna 34 with first and second arms 35 connected to ground at their distal ends by connectors 36 as the balanced antenna and a centre-fed grounded monopole antenna 28 as the unbalanced antenna.

[056] Figure 9 shows a variation of the Figure 8 embodiment with additional conductive resonators 22, 23 similar to those of the Figure 4 embodiment. Although shown here as L-shaped (or inverted L shaped), one or both of the conductive resonators 22, 23 may instead be T-shaped or another appropriate shape. The conductive resonators 22, 23 are connected to the groundplane 20 and serve to improve isolation between the WLAN/WiFi antennas 7. It is to be noted that these resonators 22, 23 are not closely coupled to the WLAN/WiFi antennas 7 and do not provide a loop-like connection to ground for the WLAN/WiFi antennas 7, since the distal ends of the arms 32 are directly connected to ground by the connectors 33.

[057] The WLAN/WiFi antennas 7 of the Figure 8 and 9 embodiments may be provided with matching circuitry to facilitate good performance in both 2.4GHz and 5.5GHz frequency bands. The use of symmetric grounded monopole antennas as the WLAN/WiFi antennas 7 is advantageous because it is easy to excite a transmission mode in the gap between the lid portion 2 and the keyboard portion 3 of the laptop computer 1, and each WLAN/WiFi antenna 7 will excite an even mode that is symmetric to the antenna 7 itself. The even mode is not easily coupled from one of the WLAN/WiFi antennas 7 to the other, thereby improving isolation.

[058] The embodiment of Figure 9 also provides good isolation of over 20dB between the WLAN/WiFi antennas 7, with the S-parameter simulation results shown in Figure 10. The upper S33 and S44 return loss plots show that each of the antennas 7 can operate in the required 2.4GHz and 5.5GHz bands.

[059] Figure 11 shows a further development of the embodiments of Figures 8 and/or 9, with additional grounded dipole antennas 37, 38 integrated with the main grounded dipole antenna 34. The additional grounded dipole antennas 37, 38 provide additional resonances and help to improve the performance of the LTE antenna 6 across a range of frequency bands.

[060] Figure 12 shows another variation, where the first and second arms 35 of the grounded dipole antenna 34 are provided with additional connectors 39 to ground, the
connectors 39 being additional to the connectors 36 at the distal ends of the arms 35. This can introduce an additional resonance.

[061] Figure 13 shows another variation, where the first and second arms 35 of the grounded dipole antenna 34 are provided with folded resonators 40. These can introduce additional resonances.

[062] Figure 14 shows another embodiment in which the grounded dipole antenna 34 is provided with a central floating loop 41. This can introduce an additional resonance.

[063] Alternatively, as shown in Figure 15, the grounded dipole antenna 34 may be provided with an additional grounded dipole antenna 42 disposed inside a footprint defined by the grounded dipole antenna 34. This can introduce an additional resonance.

[064] Figure 16 shows a variation in which the grounded dipole antenna 34 is provided with an additional grounded dipole antenna 43 extending beyond or outside a footprint defined by the grounded dipole antenna 34. This can introduce an additional resonance.

[065] Figure 17 shows an arrangement similar to that of Figure 8, except in that the grounded dipole antenna 34 is configured as a planar antenna suitable for printing or forming on a substantially planar substrate 5. In this embodiment, the substrate 5 has a substantially planar configuration, rather than being formed as a hollow rail as in Figure 4.

[066] Figure 18 shows an arrangement similar to that of Figure 12, but with a substantially planar substrate 5 and planar grounded dipole antenna 34 with first and second shorting pins 36, 39 to ground. This can introduce additional resonances.

[067] Figure 19 shows an arrangement similar to that of Figure 18, but with additional outer branches 60 on the grounded dipole antenna 34. The pins 39 and outer branches 60 may be used to generate additional resonances.

[068] Figure 20 shows an embodiment in which the grounded dipole antenna 34 is provided with a central parasitic element 50 that extends substantially parallel to the first and second arms 35. The parasitic element 50 may be used to introduce an additional resonance.

[069] Throughout the description and claims of this specification, the words "comprise" and "contain" and variations of them mean "including but not limited to", and they are not intended to (and do not) exclude other components, integers or steps. Throughout the description and claims of this specification, the singular encompasses the plural unless the context otherwise requires. In particular, where the indefinite article is used, the specification is to be understood as contemplating plurality as well as singularity, unless the context requires otherwise.
Features, integers, or characteristics described in conjunction with a particular aspect, embodiment or example of the invention are to be understood to be applicable to any other aspect, embodiment or example described herein unless incompatible therewith. All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive. The invention is not restricted to the details of any foregoing embodiments. The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

The reader's attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.
CLAIMS:

1. An antenna system disposed on an elongate dielectric substrate having a longitudinal axis with first and second opposed ends and a predetermined reference point therebetween, the antenna system comprising:
   i) a compound antenna structure disposed substantially laterally symmetrically about the reference point on the substrate, the compound antenna structure comprising at least a first unbalanced antenna with a first feed and a further antenna with a second feed; and
   ii) first and second additional unbalanced antennas disposed substantially laterally symmetrically about the compound antenna structure on the longitudinal axis of the substrate, each of the first and second additional unbalanced antennas having a respective feed.

2. The antenna system as claimed in claim 1, further comprising one or more conductive resonators on the substrate between each of the first and second additional unbalanced antennas and the compound antenna structure.

3. The antenna system as claimed in claim 2, wherein the conductive resonators are substantially L-shaped or T-shaped, with one arm extending along the longitudinal axis and the other arm extending substantially perpendicular thereto.

4. The antenna system as claimed in claim 2 or 3, wherein first and second different conductive resonators are provided between each of the additional unbalanced antennas and the central compound antenna structure.

5. The antenna system as claimed in claim 4, wherein the first and second different conductive resonators have different shapes and/or lengths.

6. The antenna system as claimed in any one of claims 2 to 5, wherein at least some of the conductive resonators are connected to ground.

7. The antenna system as claimed in claim 6, wherein the conductive resonators are connected to ground by way of an impedance.
8. An antenna system as claimed in any preceding claim, wherein the further antenna of the compound antenna structure is a second unbalanced antenna.

9. An antenna system as claimed in claim 8, wherein the first and second unbalanced antennas of the compound antenna structure are arranged substantially symmetrically about the reference point along the longitudinal axis.

10. An antenna system as claimed in any one of claims 1 to 7, wherein the further antenna of the compound antenna structure is a balanced antenna.

11. The antenna system as claimed in any preceding claim, wherein the compound antenna structure is configured as a Long Term Evolution (LTE) antenna.

12. The antenna system as claimed in any preceding claim, wherein the compound antenna structure is configured as a two-port antenna, one port comprising or being connected to the first feed and the other port comprising or being connected to the second feed.

13. The antenna system as claimed in claim 10, or in claim 11 or 12 depending from claim 10, wherein the balanced antenna of the compound antenna structure comprises a dipole antenna disposed longitudinally and substantially symmetrically about the second feed.

14. The antenna system as claimed in claim 13, wherein the dipole antenna comprises at least first and second arms fed together by the second feed and extending respectively away from each other towards the first and second opposed ends of the substrate.

15. The antenna system as claimed in claim 13 or 14, wherein the first and second arms of the dipole antenna are connected to ground.

16. The antenna system as claimed in claim 10, or in claim 11 or 12 depending from claim 10, wherein the balanced antenna is configured as a loop antenna.

17. The antenna system as claimed in claim 16, wherein part of the loop antenna is formed by first and second arms that are fed together at the second feed and extend respectively away from each other towards the first and second opposed ends of the substrate.
18. The antenna system as claimed in claim 17, wherein the first and second arms turn back towards each other and are directly joined to each other to complete the loop of the loop antenna.

19. The antenna system as claimed in claim 17, wherein the first and second arms both connect to a common groundplane, an edge of the groundplane acting to complete the loop of the loop antenna.

20. The antenna system as claimed in claim 10, or any one of claims 11 to 19 depending from claim 10, wherein the balanced antenna comprises a pair of dipole antennas, a pair of loop antennas, or a dipole antenna in combination with a loop antenna.

21. The antenna system as claimed in claim 10, or any one of claims 11 to 20 depending from claim 10, wherein the balanced antenna additionally comprises one or more parasitic radiating elements.

22. The antenna system as claimed in claim 21, wherein the parasitic element comprises a resonator loaded with a passive impedance.

23. The antenna system as claimed in claim 10, or any one of claims 11 to 22 depending from claim 10, wherein the unbalanced antenna of the compound antenna structure is configured as a monopole or chassis antenna.

24. The antenna system as claimed in claim 23, wherein the unbalanced antenna is configured as a centre-fed monopole disposed substantially symmetrically about the reference point on the substrate.

25. The antenna system as claimed in claim 10, or any one of claims 11 to 24 depending from claim 10, wherein the second feed for the balanced antenna is provided on a printed circuit board (PCB) located at the reference point on the elongate substrate.

26. The antenna system as claimed in claim 25, wherein the PCB is shaped so as to conform to a surface of the elongate substrate.

27. The antenna system as claimed in claim 26, wherein the PCB has an L-shaped profile.
28. The antenna system as claimed in any one of claims 25 to 27, wherein the PCB comprises or constitutes a groundplane that is separate from a main groundplane of the substrate of the antenna system.

29. The antenna system as claimed in claim 28, wherein the separate groundplane constituted by the PCB serves as a groundplane for the balanced antenna of the compound antenna.

30. The antenna system as claimed in any one of claims 25 to 29, wherein an impedance matching network for the balanced antenna is located on the PCB.

31. The antenna system as claimed in any one of claims 25 to 30, wherein the second feed for the unbalanced antenna is provided on the PCB.

32. The antenna system as claimed in claim 28 or any one of claims 29 to 31 depending from claim 28, wherein the unbalanced antenna of the compound antenna structure is driven against the separate groundplane of the PCB.

33. The antenna system as claimed in claim 28 or any one of claims 29 to 31 depending from claim 28, wherein the unbalanced antenna of the compound antenna structure is driven against the main groundplane of the substrate.

34. The antenna system as claimed in any preceding claim, wherein the first balanced antenna and the further antenna of the compound antenna structure are configured to excite substantially orthogonal modes.

35. The antenna system as claimed in claim 10, or any one of claims 11 to 33 depending from claim 10, wherein the balanced antenna and the unbalanced antenna of the compound antenna structure are configured to excite substantially orthogonal modes.

36. The antenna system as claimed in any preceding claim, wherein the first and second additional unbalanced antennas are configured as grounded monopole antennas.

37. The antenna system as claimed in any preceding claim, wherein the first and second additional unbalanced antennas are configured as dual-band grounded monopole antennas.
38. The antenna system as claimed in any preceding claim, wherein the first and second additional unbalanced antennas are configured as PIFAs comprising first and second branches.

39. The antenna system as claimed in claim 38, wherein the first branch includes a feed connection and a connection to ground, and the second branch extends from the first branch.

40. The antenna system as claimed in claim 38 or 39, wherein one of the first and second branches is configured to operate in a higher frequency band and the other is configured to operate in a lower frequency band.

41. The antenna system as claimed in any one of claims 1 to 37, wherein the first and second additional unbalanced antennas are each configured as substantially symmetric (along the longitudinal axis) grounded monopole antennas.

42. The antenna system as claimed in claim 41, wherein the additional unbalanced antennas each comprise an elongate strip with first and second ends extending along the longitudinal axis and provided with a central feed.

43. The antenna system as claimed in claim 42, wherein the elongate strip is connected to ground at its first and second ends.

44. The antenna system as claimed in claim 42, wherein the elongate strip is connected to ground at points between each of the first and second ends and the central feed.

45. A laptop computer comprising a lid portion attached to a keyboard portion by way of a hinge mechanism incorporating an antenna system as claimed in any one of claims 1 to 44.

46. A laptop computer as claimed in claim 45, wherein the hinge mechanism comprises first and second hinges spaced apart from each other along a hinge axis between the lid portion and the keyboard portion, and wherein the antenna system is disposed between the first and second hinges.

47. A portable device comprising an antenna system as claimed in any one of claims 1 to 44, and further comprising first and second conductive case components hinged together,
the antenna system being disposed in the hinge region between the adjacent edges of the first and second case components.

48. The portable device of claim 47, wherein the first and second conductive case components are hinged together by way of first and second hinges spaced apart from each other along a hinge axis between first and second case components, the antenna system being disposed in the hinge region between the adjacent edges of the first and second case components.
FIG. 6

FIG. 7
Graph 21

Frequency (MHz)

- ▲ DB(|S(4,4)|)
  Primary Schematic
- □ DB(|S(3,3)|)
  Primary Schematic
- ◇ DB(|S(3,4)|)
  Primary Schematic

FIG. 10
**INTERNATIONAL SEARCH REPORT**

**A. CLASSIFICATION OF SUBJECT MATTER**

INV. H01Q1/52 H01Q21/28
ADD. H01Q9/04 H01Q5/371 H01Q9/26 H01Q9/28

According to International Patent Classification (IPC), or both national classification and IPC.

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

H01Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched.

Electronic database consulted during the international search (name of database and, where practicable, search terms used)

EPO-Internal

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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Date of the actual completion of the international search: 20 September 2016
Date of mailing of the international search report: 27/09/2016

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Authorized officer:
Niemeijer, Reint
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